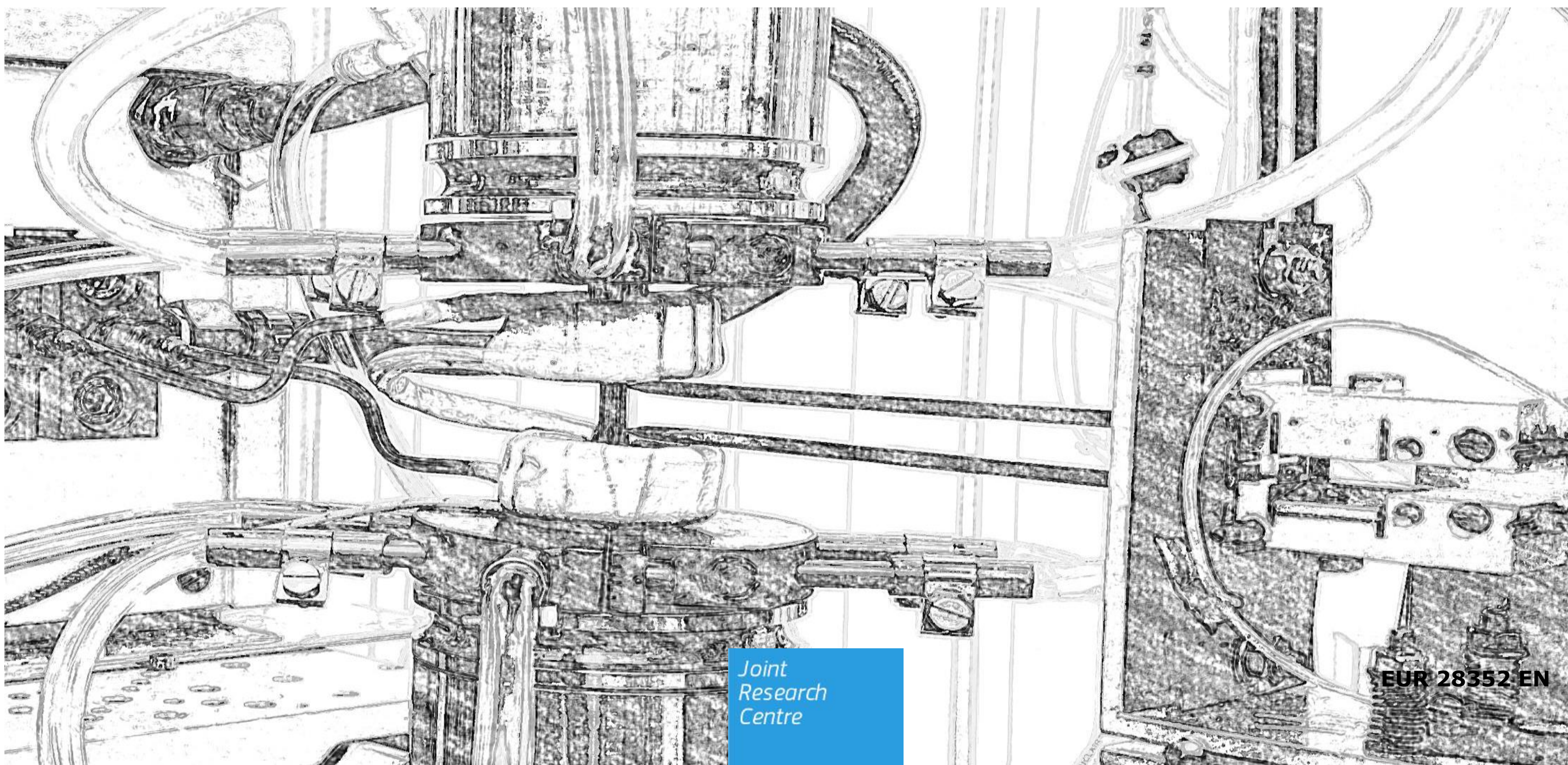
European Commission

JRC TECHNICAL REPORTS

ASTM E-2369 TMF: Inter Laboratory Study (ILS) on Strain Controlled Thermo-Mechanical Fatigue Testing

Stefan Ripplinger, Peter Haehner, Matthias Bruchhausen, Frits de Haan, Tim Austin

2016



Joint Research Centre

EUR 28352 EN

Contact information
Name: RIPPLINGER Stefan
Address: European Commission, Joint Research Centre, Directorate for Nuclear Safety and Security, Unit GI.4
E-mail: Stefan.Ripplinger@ec.europa.eu
Tel.: *+31(0)22456-5432*

JRC Science Hub
https://ec.europa.eu/jrc

JRC104385

EUR 28352 EN

ISBN 978-92-79-64623-2 (PDF)

ISSN 1831-9424 (online)

doi:10.2789/355009 (online)

How to cite: Stefan Ripplinger, Peter Haehner, Matthias Bruchhausen, Frits de Haan, Tim Austin; ASTM E-2369 TMF: Inter Laboratory Study (ILS) on Strain Controlled Thermo-Mechanical Fatigue Testing; EUR 28352 EN; doi:10.2789/355009

Table of contents

Abstract

The document presents the results of the tests conducted at the JRC Petten site, under the frame of the Inter Laboratory Study (ILS) on Thermomechanical Fatigue (ASTM E-2368). The primary purpose of this study is to provide a precision and bias statement to be included in the revision of ASTM E-2368, Standard Practice for Strain Controlled Thermo-Mechanical Fatigue Testing [1].

1. Introduction

Components which are subjected to thermomechanical loading show a degradation, which is usually greater than the sum of the resulting degradation when both types of loading are applied independently. In order to idealise the conditions, when simultaneous thermal and mechanical loading is experimentally investigated, the specimen under test is subjected to several cycles of simultaneously applied temperature and mechanical strain fields, both controlled and varied uniformly in a uniform section of the specimen. Such a test is designated as strain-controlled "thermo-mechanical fatigue", commonly abbreviated as TMF.

2. Description of Equipment

The tests were performed using an Instron test machine with tension-compression loading capability. A detailed description of the equipment used for the ILS is given in Table 1. The information is based on ASTM E-2368-4, chapter 8 [1].

Description of ASTM requirement regarding equipment	Description of equipment used
8.5.1 Loading train details including force cell type and capacity, specimen fixtures and method of gripping.	Loading train of Universal Testing Machine Instron 8862 consists of the following parts (top to bottom): Crosshead Load Cell (Instron, 2518-100, 100 kN) Alignment Tool, Instron 100kN Extension shaft Specimen Mounting Plate with thread M16 Specimen Water Cooling Plate Specimen Specimen Water Cooling Plate Specimen Mounting Plate Extension shaft Piston
8.5.2 Testing machine, including frame capacity, actuator type and capacity, and controller type.	Testing Machine: Instron 8862, 100 kN Instron Controller: FastTrack 8800
8.5.3 Test control and data collection system including all digital and analog controllers, recorders and data recording equipment.	Control Software: Instron Console Version 8.4 Build 244 TMF software: Instron TMF Version 1.4.25 Release Nov 2011 Temperature controller: Eurotherm 3504
8.5.4 Heating and cooling systems details.	Heating: Fives Celes, Inductive heating device Type Celes MP 6/400 Power 6 kW Heat exchanger Celes, GR 40-4 S Cooling power: 40 kW Water cooling plates Celes Type 40/4 S
8.5.5 Thermocouple type and specific configuration.	Thermocouple type: N Control thermocouple spot welded on the specimen. For more details see chapter "Test Methodology". Controller: Eurotherm 3504
8.5.6 Extensometer details including type, gage length, operating range and resolution.	Extensometer: Sander 1014 EX A10, travel: 0.5 mm Gauge length: 10 mm Extensometer leg extended by 15 cm ceramic rod.

Table 1: Description of Equipment:

3. Test Methodology

For the ILS on Strain Controlled Thermo-Mechanical Fatigue Testing, ASTM provided 4 identical pre-labelled TMF test coupons to each participant. JRC received coupons 65 to 68. Other than the coupons having been made of Inconel 718, no further details were revealed to the participants.

The coupon gauge length dimensions were measured at three different positions and the resulting average gauge diameter showed small deviations compared to measurements from the ASTM Cincinatti testing lab. An overview of the measurements is given in Table 2. A more detailed measurement report is presented in Annex 1. Together with all other primary data from the TMF tests, these measurements are also openly available from the European Commission materials database, MatDB [2].

Specimen Number	Gauge diameter (JRC-IET)			Average	CINCINNATI TESTING LAB
	Measurement 1	Measurement 2	Measurement 2	Gauge diameter	Gauge diameter
65	5.07	5.066	5.072	5.069	5.017
66	5.048	5.046	5.052	5.049	5.006
67	5.044	5.05	5.048	5.047	5.017
68	5.032	5.04	5.038	5.037	5.024

Table 2: Measurement results

Prior to testing, force and extensometer calibration and temperature gradient over the gauge were verified according to ASTM E2368 [1]. For details see Annexes 2-5. The calibrators used were calibrated and traceable back to international standards. Certificates of the calibrators are presented in Annexes 6-8.

The organizers of the ILS did not provide an additional TMF test coupon to be used as a dummy for the setup of the test machine. It was thus decided to use an additional TMF test coupon of identical geometry and similar material properties for the setup procedure. Udimet 720 (Ni-base alloy) was chosen as the dummy test coupon material.

For the calibration of the thermal stability, 5 N type thermocouples were spot-welded on the dummy test coupon. Figure 1 illustrates the positions of the thermocouples based on the middle of the gauge length. The extensometer gauge length was 10 mm.

The maximum allowable axial temperature gradient over the gauge at any given instant in time within the cycle shall be ≤ 9°C, according to ASTM E-2368 [1]. A flat axial temperature gradient in gauge length increases the risk of specimen failure outside the extensometer gauge. For that reason it was decided to accept a higher axial temperature gradient over the gauge and a less flat temperature profile. A thermal cycle is illustrated in Figure 2, together with the axial temperature gradient (which in our case was ≤ 16°C). The temperature profile is plotted along the gauge length in Figure 3.

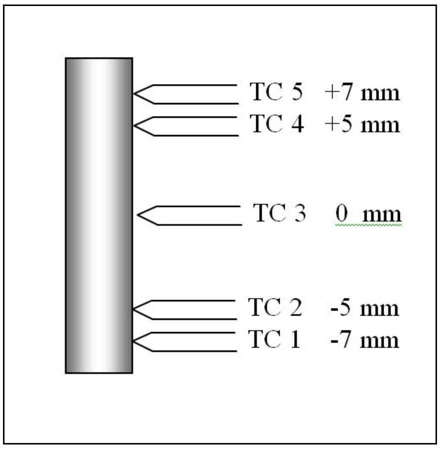


Figure 1: Positioning of the attached thermocouples

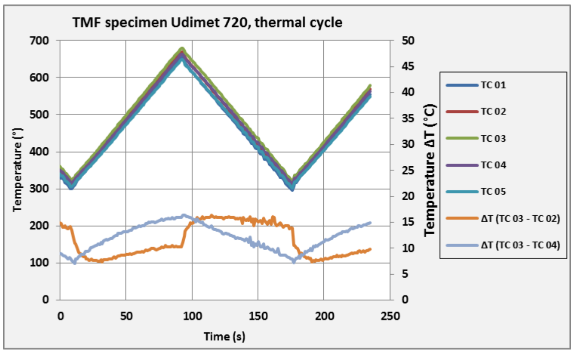


Figure 2: Thermal cycle

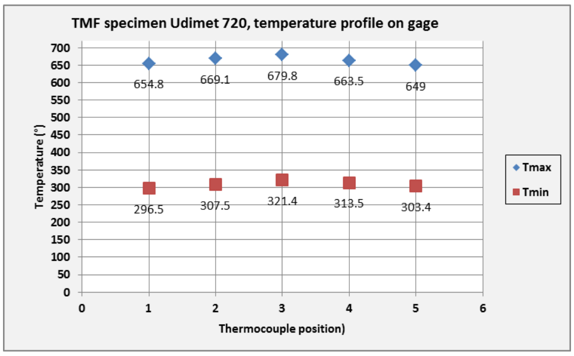


Figure 3: Temperature profile

Coupon 65 was tested using only TC1 following the temperature profile. This coupon has fractured outside the gauge length, on the position of the spot welded thermocouple, which is considered as an invalid test. For that reason it was decided to move the position of the control thermocouple to -9mm, keeping the same temperature profile, while establishing a new relationship between TC1 and TC3, according to the graphs in Figures 4 and 5.

Coupons 66-68 were tested according to the new thermal relationship and have resulted in fracture inside the gauge length. More details on the test methodology are displayed in Table 3.

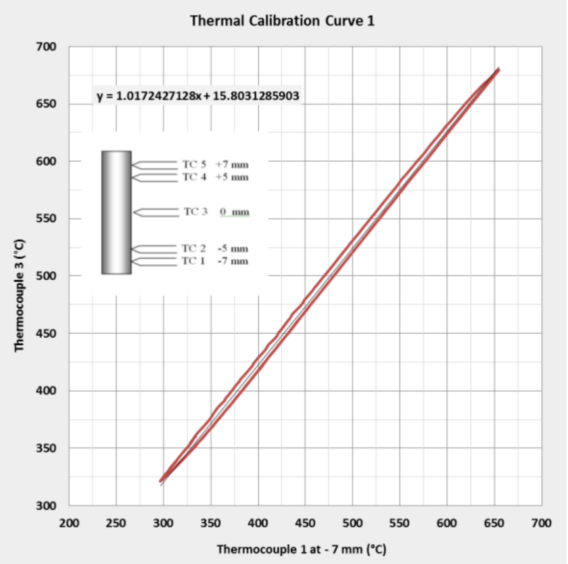


Figure 4: Thermal calibration curve 1

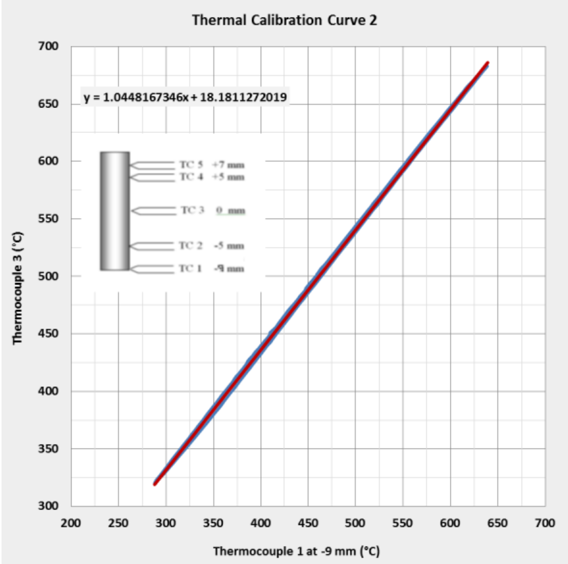


Figure 5: Thermal calibration curve 2

Description of ASTM requirement regarding methodology	**Description of actual methodology followed**
8.6.1 Details describing the approach used for thermal strain compensation and verification of the accuracy of the approach.	The Instron TMF software is using an automatic start-up procedure for TMF testing. In the first sequence a thermal strain compensation test is performed in force control mode. The average thermal strain of 3 cycles is calculated and used as a control signal for the subsequent zero stress test. The TMF test starts automatically if the recorded stress level is within a predefined level of ± 30 MPa.
8.6.2 Details describing the approach	The temperature and mechanical phase

used for maintaining accurate temperature/mechanical strain phasing and verification of the accuracy of the approach.	shift are controlled and recorded automatically during execution of TMF-test by the TMF program
8.6.3 Details describing the approach to temperature control and monitoring.	For the calibration of the thermal stability, 5 N type thermocouples were spot-welded on a dummy test coupon. Figure 1 illustrates the positions of the thermocouples based on the middle of the gauge length. After a stabilisation phase of approximately 10 temperature cycles, the following 3 cycles were recorded and averaged. The thermal relationship between thermocouple 1 and 3 were calculated and thermocouple 1 only was used to control the temperature cycle of the TMF test. The thermal relationship for coupon 65 is depicted in figure 4 and for coupons 66 – 68 in figure 5. During execution of the TMF test thermocouple 1 is used to control the temperature profile and the actual temperature signal is recorded.
8.6.4 Details describing the approach to commencement of the TMF loadings.	The Instron TMF software is using an automatic start-up procedure for TMF testing. In the first sequence a thermal strain compensation test is performed in force control mode. The average thermal strain of 2 cycles is calculated and used as a control signal for the subsequent zero stress test. The TMF test starts automatically if the recorded stress level is within a predefined level of ± 30 MPa.
8.6.5 Definition of failure.	90 % load drop
8.6.6 Deviations from recommended test procedures.	Axial temperature gradient: ± 16°C; For details see chapter "Test Methodology".

Table 3: Test Methodology

4. Summary of Results

The results were automatically recorded by the Instron software and all the primary data are published in an Open Access catalog and can be exported in different formats [2]. As an example, a plot of the force versus the number of cycles is presented in Figure 6.

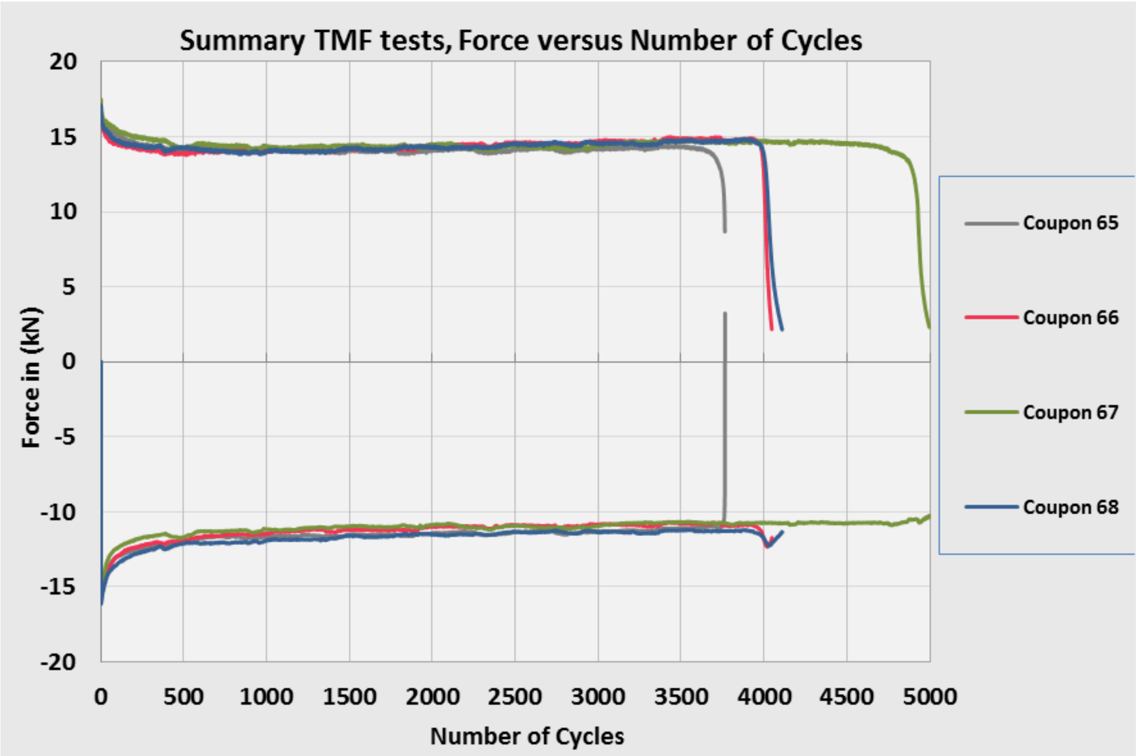


Figure 6: Force versus Number of Cycles

Table 4 lists the TMF results, including failure position and number of cycles.

Specimen number	Mech Strain Range (%)	Max Strain (%)	Min Strain (%)	Temp. Max (°C)	Temp. Min (°C)	Waveform	Cycle Time (s)	Specimen Length (mm)	Gauge Length (mm)	OD (mm)	ID (mm)	Area (mm2)	Actual Life (cycles)	Failer Location (degrees)	Failer Position (ID/OD)	Notes
65	1	0.5	-0.5	677	316	Ttrangular	180	112	9.99	5.069		20.181	3764	150°	TC reff	
66	1	0.5	-0.5	677	316	Ttrangular	180	112	9.992	5.049		20.022	4047	345°	in gauge	
67	1	0.5	-0.5	677	316	Ttrangular	180	112	9.997	5.047		20.006	4998	285°	in gauge	
68	1	0.5	-0.5	677	316	Ttrangular	180	112	10.011	5.037		19.927	4109	165°	in gauge	

Table 4 Summary of TMF results

References

1. ASTM E 2368-04; Standard Practice for Strain Controlled Thermomechanical Fatigue Testing

2. Ripplinger, S (2016): MatDB Catalog of JRC Open Access TMF Test Data Created in the Scope of an ASTM Inter Laboratory Study, version 1.0, European Commission JRC, [Catalog], http://dx.doi.org/10.5290/10.

List of Annexes

Annex 1: Verification of TMF specimen

Verification of TMF specimens "ILS-20"

Verification date: 08.06.2015
Micrometer gauge: TESA MICROMASTER
0 - 25 mm, Precision: 0.002
Serial number: 56 10000
Gauge block: Mitutuyo 1-100 mm
Serial number: 301869
Calibration certificate: 12506389.1000.1/RI

The micrometer gauge has been verified using the gauge block set prior measurements. The error of the measurement instrument was within the acceptable area.

Specimen Number	Gauge diameter (JRC-IET)			Average	CINCINNATI TESTING LAB
	Measurement 1	Measurement 2	Measurement 3	Gauge diameter	Gauge diameter
65	5.07	5.066	5.072	5.069	5.017
66	5.048	5.046	5.052	5.049	5.006
67	5.044	5.05	5.048	5.047	5.017
68	5.032	5.04	5.038	5.037	5.024

Annex 2: Load train alignment

Instron AlignPRO Report File	

Copyright © Instron 2010	Hardware ID:=AP-USB-350-01 [A]
File created: 5/24/2016 13:36:33	Description:=16 ch
	Alignment Cell Type:=Custom
[Format]	Alignment Cell:=Instron alignment specimen
App=AlignPRO Wizard	Cell Description:=cylindrical:8
Version=2.1.5	Material:=steel
List Separator=	Total Length (lt):=150.0 mm
Decimal Separator=.	Length (l):=50.0 mm
	Diameter (Ø):=8.0 mm
[Setup Parameters]	Area:=50.3 mm²
Operator:= frits de haan	Count:=8
Reference Nº:= no 1	Type:=350 ohms
Temperature:=22 °C	Factor:=2.00
Frame ID:= 8862H2012	Separation (lg):=0.0 mm
Date:=11:29 am - 24/May/16	Attachment:=
Company:= JRC	Alignment Force:=2.0 kN
Address:= westerduinweg 3	Cell Compensation:=Off
Specification:=ASTM E1012 : 2005	Test Comments:=Alingment 24 may 2016 Start TMF tests
Unit System:=S.I.	
16 bit device with USB interface	

[Alignment Summary]

Field Name	**e1 (µE)**	**e2 (µE)**	**e3 (µE)**	**e4 (µE)**	**Average**	**b1 (µE)**	**b2 (µE)**	**b3 (µE)**	**b4 (µE)**	**Max Bending (µE)**	**% Bending**
Top Gauges=	198.72	187.22	185.14	193.04	191.03	7.69	-3.81	-5.89	2.01	7.39	3.87
Bottom Gauges=	185.94	184.76	192.84	185.61	187.29	-1.35	-2.53	5.56	-1.68	3.48	1.86

Annex 3: Extensometer verification

EXTENSOMETER VERIFICATION REPORT							
JRC-IET Petten, the Netherlands							
Performed for:	ASTM ILS-20					Date: 25 April 2016	
Operator:	f.j. de haan						
Extensometer:	Sandner			Machine:	INSTRON		
Model:	AX A10 - 0.5			Model:	8862		
Serial No.:	1014			Serial No.:	H2012		
Tens F/s Travel:	0.5			Indicators:	Console Version 8.4		
Gauge Length:	10 mm						
Test Type: Unidirectional		Temperature:	22°C	Machine Strain Channel: second channel			
GAUGE LENGTH MEASURED (DIRECT):		(Direct) : 1)	9.992 mm 2)	9.9835	mm		
ERROR IN GAUGE LENGTH:		0.0165 mm	→	0.165%			

ACTUAL STRAIN (%)		EXTENSOMETER STRAIN (%)		FIXED ERROR (mm/mm)		RELATIVE ERROR (% OF ACT. STRAIN)	
RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2
0.00000	1.00165	0.000	1.007	0.0000000	-0.0000501	0.0000	0.5000
0.10017	0.90149	0.101	0.906	-0.0000050	-0.0000501	0.5000	0.5556
0.20033	0.80132	0.202	0.804	-0.0000150	-0.0000300	0.7500	0.3750
0.30050	0.70116	0.303	0.705	-0.0000250	-0.0000351	0.8333	0.5000
0.40066	0.60099	0.403	0.602	-0.0000200	-0.0000150	0.5000	0.2500
0.50083	0.50083	0.504	0.502	-0.0000351	-0.0000100	0.7000	0.2000
0.60099	0.40066	0.604	0.401	-0.0000300	-0.0000050	0.5000	0.1250
0.70116	0.30050	0.705	0.300	-0.0000401	0.0000000	0.5714	0.0000
0.80132	0.20033	0.806	0.200	-0.0000451	0.0000050	0.5625	-0.2500
0.90149	0.10017	0.906	0.100	-0.0000451	0.0000050	0.5000	-0.5000
1.00165	0.00000	1.007	0.001	-0.0000501	-0.0000050	0.5000	0.0000

ACTUAL STRAIN (%)		EXTENSOMETER STRAIN (%)		FIXED ERROR (mm/mm)		RELATIVE ERROR (% OF ACT. STRAIN)	
RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2	RUN 1	RUN 2
0.00000	-1.00165	0.000	-0.999	0.0000000	-0.0000300	0.0000	-0.3000
-0.10017	-0.90149	-0.100	-0.898	0.0000000	-0.0000300	0.0000	-0.3333
-0.20033	-0.80132	-0.200	-0.798	0.0000000	-0.0000300	0.0000	-0.3750
-0.30050	-0.70116	-0.300	-0.700	-0.0000050	-0.0000150	-0.1667	-0.2143
-0.40066	-0.60099	-0.400	-0.599	-0.0000100	-0.0000150	-0.2500	-0.2500
-0.50083	-0.50083	-0.499	-0.499	-0.0000150	-0.0000150	-0.3000	-0.3000
-0.60099	-0.40066	-0.599	-0.399	-0.0000150	-0.0000150	-0.2500	-0.3750
-0.70116	-0.30050	-0.700	-0.298	-0.0000100	-0.0000200	-0.1429	-0.6667
-0.80132	-0.20033	-0.799	-0.199	-0.0000250	-0.0000150	-0.3125	-0.7500
-0.90149	-0.10017	-0.898	-0.099	-0.0000300	-0.0000100	-0.3333	-1.0000
-1.00165	0.00000	-0.999	-0.001	-0.0000300	0.0000050	-0.3000	0.0000

CALIBRATION FACTOR (Converts Machine Output to Strain Value):				
RESOLUTION: 0.0001 mm			CLASS OF EXTNSOMETER SYSTEM: C	
VERIFICATIOM METHOD:	Hologage Mitutoyo Corperation			
VERIICATION APPARATUS:	Laser LVDT			
Laser-Hologage – Model:	LGH - 1010			
	Serial No.:		10981	
	Calibration Due:		11.06.2014	
	Calibration Certificate:		1401778.2.1	

Annex 4: Force calibration

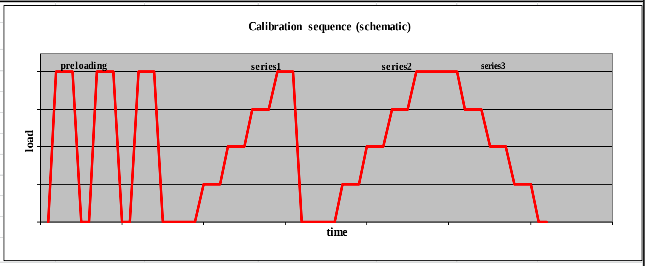
Results of LOAD signal calibration

(Reference: DIN 10002-3)

Machine:	Instron III	**Tester:**	Frits de haan
Place:	Building 325	**Date:**	30.04.2016
Type:	Load-cell, type: 2518-100	**Temperature**	24 °C
Manufacturer:	Instron		
Serial – Nr.:	G14192	**Remarks:**	
Calibration range:	-50 kN +50 kN		

Preload loadcell until maximum of calibration range in tension (3times)

Nominal machine value indicated in kN	Nominal value indicated	hold time (s)
max. cal. range	50.143	60-90
0.00	0.175	min. 30
max. cal. range	50.088	60-90
0.00	0.003	min. 30
max. cal. range	50.063	60-90
0.00	0.002	min. 30

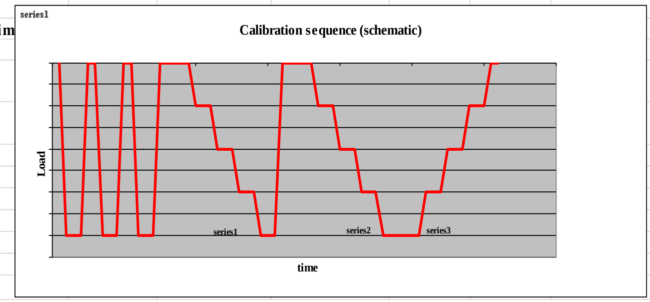


tension

series 1			series2				series3			
Nominal machine value indicated in kN	Calibrator values in kN (X_1)	Relative bias error q in %	Nominal machine value indicated in kN	Calibrator values in kN (X_2)	Relative bias error q in %	$b'=2(X_2-X_1)/(X_1+X_2)*100\%$	Nominal machine value indicated in kN	Calibrator values in kN (X_3)	Relative bias error q in %	$u = 2(X_3-X_2)/(X_3+X_2)*100\%$
0.00	0.000		0.00	0.000						
5.00	4.999	-0.02%	5.00	4.999	-0.02%	0.000%	50.00	50.076	0.15%	-0.010%
10.00	10.014	0.14%	10.00	10.009	0.09%	-0.050%	45.00	45.123	0.27%	0.115%
15.00	15.023	0.15%	15.00	15.020	0.13%	-0.020%	40.00	40.051	0.13%	-0.065%
20.00	20.017	0.08%	20.00	20.025	0.12%	0.040%	35.00	35.090	0.26%	0.091%
25.00	25.039	0.16%	25.00	25.038	0.15%	-0.004%	30.00	30.040	0.13%	0.010%
30.00	30.038	0.13%	30.00	30.037	0.12%	-0.003%	25.00	25.040	0.16%	0.008%
35.00	35.050	0.14%	35.00	35.058	0.17%	0.023%	20.00	20.038	0.19%	0.065%
40.00	40.071	0.18%	40.00	40.077	0.19%	0.015%	15.00	15.032	0.21%	0.080%
45.00	45.054	0.12%	45.00	45.071	0.16%	0.038%	10.00	10.015	0.15%	0.060%
50.00	50.082	0.16%	50.00	50.081	0.16%	-0.002%	5.00	5.005	0.10%	0.120%
0.00	0.017		0.00	0.008			0.00	0.006		
$f_{o(series1)} = X_1(0)/X_1(max)*100\%$			$f_{o(series2)} = X_2(0)/X_{2(max)}*100\%$							
$f_{o(series1)} =$	0.000		$f_{o(series2)} =$	0.02%	$b'_{max} =$	0.050%			$u_{max} =$	0.120%

Preload loadcell until maximum of calibration range in compression (3tim

Nominal machine value indicated in kN	Nominal machine value indicated in kN	hold time (s)
max. cal. range	-49.942	60-90
0.00	-0.046	min. 30
max. cal. range	-49.897	60-90
0.00	-0.013	min. 30
max. cal. range	-49.895	60-90
0.00	-0.014	min. 30



compression

series 1			series2				series3			
Nominal machine value indicated in kN	Calibrator values in kN (X_1)	Relative bias error q in %	Nominal machine value indicated in kN	Calibrator values in kN (X_2)	Relative bias error q in %	$b'=2(X_2-X_1)/(X_1+X_2)*100\%$	Nominal machine value indicated in kN	Calibrator values in kN (X_3)	Relative bias error q in %	$u = 2(X_3-X_2)/(X_3+X_2)*100\%$
0.00	0.000		0.00	0.000						
-5.00	-4.982	-0.37%	-5.00	-4.987	-0.27%	0.100%	-50.00	-49.878	-0.24%	0.000%
-10.00	-9.969	-0.31%	-10.00	-9.976	-0.24%	0.070%	-45.00	-44.928	-0.16%	0.091%
-15.00	-14.957	-0.29%	-15.00	-14.963	-0.25%	0.043%	-40.00	-39.890	-0.28%	-0.021%
-20.00	-19.943	-0.29%	-20.00	-19.949	-0.25%	0.033%	-35.00	-34.916	-0.24%	0.014%
-25.00	-24.933	-0.27%	-25.00	-24.940	-0.24%	0.028%	-30.00	-29.915	-0.28%	-0.033%
-30.00	-29.919	-0.27%	-30.00	-29.925	-0.25%	0.022%	-25.00	-24.940	-0.24%	0.000%
-35.00	-34.910	-0.26%	-35.00	-34.913	-0.25%	0.009%	-20.00	-19.948	-0.26%	-0.005%
-40.00	-39.893	-0.27%	-40.00	-39.898	-0.25%	0.013%	-15.00	-14.962	-0.26%	-0.010%
-45.00	-44.879	-0.27%	-45.00	-44.887	-0.25%	0.018%	-10.00	-9.974	-0.26%	-0.015%
-50.00	-49.875	-0.25%	-50.00	-49.878	-0.24%	0.007%	-5.00	-4.982	-0.36%	-0.090%
0.00	-0.010		0.00	-0.006			0.00	-0.004		
$f_{o(series1)} = X_1(0)/X_1(max)*100\%$			$f_{o(series2)} = X_2(0)/X_{2(max)}*100\%$							
$f_{o(series1)} =$	0.000		$f_{o(series2)} =$	0.01%	$b'_{max} =$	0.100%			$u_{max} =$	0.091%

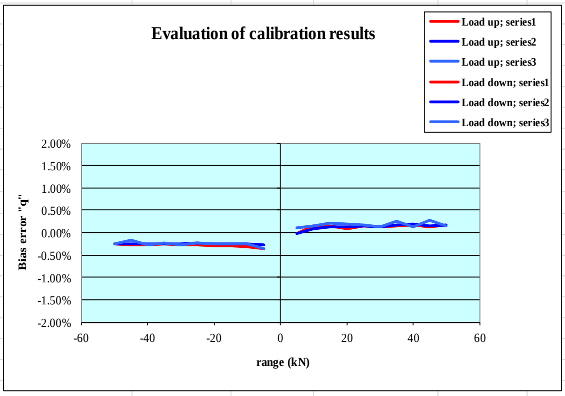
Calibration values evaluation

Table 2: Characteristics of the load cells (DIN 10002-3)

Class	relative error margin of load-cell					calibration force
	span		interpolation error	zero error	reversal error	measurement uncertainty
	b	b'	f_c	f_o	u	%
00	0.050	0.025	+/- 0.025	+/- 0.025	0.07	+/- 0.01
0,5	0.100	0.05	+/- 0.05	+/- 0.05	0.15	+/- 0.02
1	0.200	0.1	+/- 0.10	+/- 0.10	0.3	+/- 0.05
2	0.400	0.2	+/- 0.20	+/- 0.20	0.5	+/- 0.10

Calibration results:

	span	zero error		reversal error	bias error
	b'	f_o		u	$q_{(max)}$
		series1	series2		
tension	0.050%	0.03%	0.02%	0.120%	0.17%
compression	0.100%	0.02%	0.01%	0.091%	0.37%
class	1	1	1	0.5	



Calibration equipment:

Digital Measuring Unit DK38	**ID.Nr: 89.00040**
Load cell Type: Z3H2K	**ID.Nr: D42047**

Calibration pass criteria	
span "b"	0.2
zero error fo	+/-0.2
rev. error "u"	0.5
bias error "q"	2%

Person in charge:..

Annex 5: Temperature controller calibration

Results of Themperature controller calibration

(Reference: DIN 10002-3)

Machine:	Instron III	**Tester:**	Frits de haan
Place:	Building 325	**Date:**	30.04.2016
Type:	3504	**Temperature:**	24 °C
Manufacturer:	Eurotherm		
Calibrated channel:	Input	**Remarks:**	
Thermocouple:	N-type		

Calibration device:	
Type:	Calys 50
Manufacturer:	AOIP
Serial - Nr.:	WEM41001000
Calibration certificate:	1502429.6.1

series 1			series2		
Nominal value indicated in °C	Eurotherm 3504 values in °C (X_1)	Relative bias error q in %	Nominal value indicated in °C	Eurotherm 3504 values in °C (X_2)	Relative bias error q in %
0.0	0.6		1300.0	1301.0	
100.0	100.4	0.40%	1200.0	1200.9	0.08%
200.0	200.5	0.25%	1100.0	1100.8	0.07%
300.0	300.5	0.17%	1000.0	1000.8	0.08%
400.0	400.6	0.15%	900.0	900.7	0.08%
500.0	500.5	0.10%	800.0	800.7	0.09%
600.0	600.6	0.10%	700.0	700.7	0.10%
700.0	700.7	0.10%	600.0	600.7	0.12%
800.0	800.8	0.10%	500.0	500.6	0.12%
900.0	900.8	0.09%	400.0	400.6	0.15%
1000.0	1000.9	0.09%	300.0	300.6	0.20%
1100.0	1100.8	0.07%	200.0	200.5	0.25%
1200.0	1200.9	0.08%	100.0	100.5	0.50%
1300.0	1301.0	0.08%	0.0	0.5	
	Bias error $q_{(max)}$:	**0.40%**		**Bias error $q_{(max)}$:**	**0.50%**

Annex 6: Multi-Function calibrator

MetricControl

CERTIFICAAT

nummer 1502429.6.1

Aanvrager	GCO Westerduinweg 3 1755 LE Petten	
Onderzocht	Calibrator Fabrikaat Type Serienummer	 : AOIP : Calys 50 : WEM41001000
Wijze van onderzoek	Meting(en) uitgevoerd conform procedure Calys50_AOIP	
Resultaat	Zie volgblad(en) De resultaten zijn, daar waar mogelijk, getoetst aan specificatie. Afwijkingen zijn, indien mogelijk, gekenmerkt.	
Onderzoeksdatum	27 juli 2015	
Omgevingscondities	Temperatuur	: (23,0 ± 3,0) °C
Herleidbaarheid	De bij het onderzoek gebruikte meetmiddelen zijn herleidbaar naar primaire en/of (inter)nationale standaarden.	
Onzekerheid	De gerapporteerde onzekerheid is gebaseerd op een standaardonzekerheid, vermenigvuldigd met een dekkingsfactor *k=2*, welke overeenkomt met een betrouwbaarheidsinterval van ongeveer 95%. De meetonzekerheid is bepaald volgens EA-4/02.	

Keuren en Kalibreren B.V.
27 juli 2015

Ing. J.A. Hemmes
Directeur

1031.841-10005 Wonderen, C.P.J. van

Keuren en Kalibreren B.V.
KvK nr. 55251757
Smaragdstraat 7
7554 TD Hengelo
T +31 (0)74 250 34 44
F +31 (0)74 250 37 77
kalibraties@metriccontrol.nl
www.metriccontrol.nl

MetricControl
Bankrekeningnummer: ABNAMRO 475472217
Swift/IBAN: NL18ABNA0475472217
BIC: ABNANL2A
BTW nr. NL851626087B01

MetricControl
Handelsmerk Keuren en Kalibreren

Geaccrediteerd conform:
NEN-EN-ISO 17025:2005
Gecertificeerd conform:
NEN-EN-ISO 9001:2008

CERTIFICAAT

Gebruikte meetmiddelen

Fabrikaat / type	Registratienummer
Datron 9100	nr. A0028
Datron 1281	nr. X50051
Burster 4421	nr. X50054

CERTIFICAAT

nummer 1502429.6.1
blad 3 van 4

Measurement result

Test		Readout	Required	Uncert.	Unit
IN (measure)					
DC Current					
Range:	Connected:				
50	0	0,000	0 ± 0,02	0,001	mA
	20	19,998	20 ± 0,02	0,001	mA
	50	49,988	50 ± 0,02	0,001	mA
DC Voltage					
Range:	Connected:				
100	0	0,000	0 ± 0,02	0,01	mV
	20	19,997	20 ± 0,02	0,01	mV
	50	49,995	50 ± 0,02	0,01	mV
1	0,2	0,19999	0 ± 0,02	0,01	V
	0,5	0,49997	0,5 ± 0,02	0,01	V
	0,8	0,79989	0,8 ± 0,02	0,01	V
10	2	1,9997	2 ± 0,02	0,01	V
	5	4,9988	5 ± 0,02	0,02	V
	8	7,9980	8 ± 0,02	0,02	V
50	20	19,996	20 ± 0,02	0,05	V
	50	49,994	50 ± 0,02	0,05	V
Temperature					
Range:	Connected:				
Couple K	0	0,01	0 ± 0,3	0,2	℃
	100	100,02	100 ± 1,0	0,2	℃
	500	500,52	500 ± 1,5	0,2	℃
Resistance					
Range:	Connected:				
400	0	0,027	0 ± 0,05	0,01	Ω
	20	20,029	20 ± 0,05	0,01	Ω
	100	100,029	100 ± 0,10	0,10	Ω
	350	350,025	350 ± 0,50	0,10	Ω
4000	1000	1000,17	1000 ± 1,00	0,20	Ω
	3500	3500,15	3500 ± 1,00	0,20	Ω

CERTIFICAAT

Test		Calibrator	Required	Uncert.	Unit
OUT (Generate)					
DC Current					
Range:	Generated:				
24	1	1,0001	1 ± 0,002	0,001	mA
	15	15,0012	15 ± 0,005	0,001	mA
	24	24,0060	24 ± 0,01	0,001	mA
DC Voltage					
Range:	Generated:				
100	100	100,011	100 ± 0,02	0,01	mV
2	2	2,00029	2 ± 0,001	0,01	V
20	20	20,0019	20 ± 0,005	0,01	V
Temperature					
Range:	Generated:				
Couple K	0	-0,1	0 ± 0,3	0,2	℃
	100	100,0	100 ± 1,0	0,2	℃
	500	499,8	500 ± 1,5	0,2	℃
Resistance					
Range:	Generated:				
40	0	0,012	0 ± 0,05	0,01	Ω
	20	20,017	20 ± 0,05	0,01	Ω
400	50	50,018	50 ± 0,05	0,01	Ω
	100	100,021	100 ± 0,10	0,10	Ω
	350	350,021	350 ± 0,50	0,10	Ω
4000	1000	1000,10	1000 ± 1,00	0,20	Ω
	3500	3500,09	3500 ± 1,00	0,20	Ω

Annex 7: Load-cell calibration

CERTIFICAAT

nummer 15202876.1000.1NL/R1
blad 1 van 6

Aanvrager	GCO Westerduinweg 3 1755 PETTEN
Onderzocht	Trek- / drukkrachtmeter voor algemeen gebruik fabrikaat : HBM - Darmstadt type : Z3H2 K identificatie : D42047 capaciteit : 50 kN
Meetgebied(en)	De kalibratie is van 2 kN tot 50 kN uitgevoerd.
Onderzoekswijze	Vergelijking van de krachtsaanwijzing of –instelling met kalibratiestandaarden volgens de in NEN-EN 12390-4 en/of NEN-EN-ISO 7500-1 omschreven procedure.
Omgevingstemp.	(20,0 ± 0,5)°C
Onderzoeksdatum	Het onderzoek werd verricht op 7 augustus 2015.
Conclusie	De krachtsaanwijzing voldoet aan de betreffende eisen volgens NEN-EN-ISO 7500-1 klasse 1 en/of NEN-EN 12390-4 klasse 1, met een ondergrens van 2 kN. Voor krachtmeters in gebruik bij de offshore of de bouw zijn geen aparte normen opgesteld. De kalibratie uitkomsten worden daarom getoetst aan NEN-EN-ISO 7500-1 trekbanken voor metalen of aan NEN-EN 12390-4 drukbanken voor beton.
Resultaat	Het resultaat is weergegeven op het (de) volgblad(en).
Herleidbaarheid	De bij het onderzoek gebruikte meetmiddelen zijn herleidbaar naar primaire en/of (inter)nationale standaarden.
Plaats van opstelling	Laboratorium van NMi te Dordrecht.
Aanwijzing	HBM meetversterker type DK38 serienummer 29061 met een digitale aanwijsschaal.

NMi Certin B.V.
18 augustus 2015

C. Oosterman
Hoofd Certificatiebestuur

pct-001 2009-01-NL
Duin, A.P. van

NMi Certin B.V.
Hugo de Grootplein 1
3314 EG Dordrecht
Nederland
T +31 (0)78 633 23 20
krachtkalibraties@nmi.nl
www.nmi.nl

KALIBRATIE

CERTIFICAAT

nummer 15202876.1000.1NL/R1
blad 2 van 6

Justering	Het onderzoek is uitgevoerd zonder dat justering heeft plaatsgevonden.
Afwijkingen	q_{max} = 0,4% van F_A b_{max} = 0,2% van F_A $F_{0,max}$ = 0,0% van F_N
Afleeswaarde	a $\leq$ 0,50 % van de ondergrens
Onzekerheid	Kracht 0,25 % van F_W; De gerapporteerde onzekerheid is gebaseerd op een standaardonzekerheid, vermenigvuldigd met een dekkingsfactor *k = 2*, welke overeenkomt met een betrouwbaarheidsinterval van ongeveer 95%. De standaardonzekerheid is bepaald volgens EA-4/02.
Gebruikte meetmiddelen	23010262 Meetversterker HBM DK38 nr.46545 53001350 Krachtopnemer TD93 50kN

SYMBOLEN EN DEFINITIES VOOR DE KALIBRATIE VAN TREK- , DRUK- , EN BUIGBANKEN

F_N	Maximum krachtsaanwijzing van een meetgebied in N
F_A	Krachtsaanwijzing van de beproevingsmachine met toenemende kracht in N
F_c	Aanwijzing van de kalibratie krachtmeter in mV/V
F_W	Uit F_c berekende, werkelijk gemeten gemiddelde kracht in N
F_{A1} , F_{C1} , F_{W1}	Als F_A, F_c en F_W , echter met afnemende kracht in N
F_{Amax} , F_{Amin}	Hoogste en laagste waarde van F_A
F_{Wmax} , F_{Wmin}	Hoogste en laagste waarde van F_W
F_{A0}	Resterende krachtsaanwijzing na het wegnemen van de kracht
F_{Ad}	Krachtaanwijzing, 15 min na het ontlasten (a.g.v. mogelijke drift in elektronische meetapparatuur)
A_r	Afleesmogelijkheid (schattingswaarde) in N
q	Relatieve nauwkeurigheidsafwijking $\frac{F_A - F_W}{F_W}$ x 100%
b	Relatieve herhaalbaarheidsafwijking $\frac{F_{Wmax} - F_{Wmin}}{F_W}$ x 100%
u	Relatieve omkeerfout $\frac{F_W - F_{W1}}{F_W}$ x 100% (wordt uitsluitend op verzoek bepaald)
a	Relatieve afleeswaarde bij de ondergrens $\frac{A_r}{F_W}$ x 100%
r	Resolutie $\frac{A_r}{F_N}$ x 100%
f_0	Relatieve nulpuntsfout $\frac{F_{A0}}{F_N}$ x 100%
f_d	Relatieve nulpuntsdrift (na 15 min) $\frac{F_{Ad}}{F_N}$ x 100% (a.g.v. mogelijke drift in elektronische meetapparatuur)

CERTIFICAAT

EISEN VOOR DE KALIBRATIE

Uniaxiale trek/drukbanken voor metalen volgens NEN-EN-ISO 7500-1

Klasse bank	Maximum toelaatbare waarde in elk meetgebied in %				
	q	b	u	a	f_0
0,5	± 0,5	0,5	0,75	0,25	± 0,05
1	± 1,0	1,0	1,5	0,5	± 0,1
2	± 2,0	2,0	3,0	1,0	± 0,2
3	± 3,0	3,0	4,5	1,5	± 0,3

Drukbanken voor beton volgens NEN-EN 12390-4

Klasse drukbank	Maximum toelaatbare waarde in elk meetgebied in %			
	q	b	f_0	a
1	± 1,0	1,0	± 0,2	0,5
2	± 2,0	2,0	± 0,4	1,0
3	± 3,0	3,0	± 0,6	1,5

CERTIFICAAT

Meetgebied 50 kN

Tabel 1. Trekbelasting

$\bar{F}_A$ kN	$F_{W,1}$ kN	$F_{W,2}$ kN	$F_{W,3}$ kN	$\bar{F}_W$ kN	q %	b %
2,0000	1,9927	1,9962	1,9927	1,9939	0,3	0,2
3,0000	2,9883	2,9933	2,9893	2,9903	0,3	0,2
5,0000	4,9797	4,9822	4,9817	4,9812	0,4	0,1
10,000	9,9587	9,9632	9,9665	9,9628	0,4	0,1
15,000	14,942	14,953	14,944	14,946	0,4	0,1
20,000	19,919	19,947	19,929	19,931	0,3	0,1
25,000	24,908	24,916	24,909	24,911	0,4	0,0
30,000	29,890	29,898	29,891	29,893	0,4	0,0
35,000	34,885	34,889	34,869	34,881	0,3	0,1
40,000	39,853	39,854	39,858	39,855	0,4	0,0
45,000	44,835	44,844	44,849	44,843	0,4	0,0
50,000	49,819	49,826	49,824	49,823	0,4	0,0
0				0		

CERTIFICAAT

nummer 15202876.1000.1NL/R1

Meetgebied 50 kN

Tabel 2. Drukbelasting

$\bar{F}_A$ kN	$F_{W,1}$ kN	$F_{W,2}$ kN	$F_{W,3}$ kN	$\bar{F}_W$ kN	q %	b %
2,0000	1,9979	1,9994	2,0009	1,9994	0,0	0,2
3,0000	2,9974	2,9999	2,9984	2,9985	0,0	0,1
5,0000	4,9952	4,9925	4,9947	4,9941	0,1	0,1
10,000	9,9913	9,9865	9,9828	9,9868	0,1	0,1
15,000	14,976	14,975	14,988	14,980	0,1	0,1
20,000	19,957	19,959	19,965	19,960	0,2	0,0
25,000	24,946	24,947	24,946	24,946	0,2	0,0
30,000	29,934	29,936	29,934	29,934	0,2	0,0
35,000	34,927	34,918	34,914	34,920	0,2	0,0
40,000	39,902	39,918	39,892	39,904	0,2	0,1
45,000	44,898	44,884	44,892	44,892	0,2	0,0
50,000	49,873	49,870	49,875	49,872	0,3	0,0
0				0		

Annex 8: Mitutuyo Laser Hologage calibration

MetricControl **CERTIFICAAT**

nummer 1401778.2.1
blad 1 van 2

Aanvrager	GCO Westerduinweg 3 1755 LE Petten
Onderzocht	Elektronische taster met digitale uitlezing Fabrikaat : Mitutoyo Type : EF-11PRH Serienummer : 003040
Wijze van onderzoek	Als eerste werd de opstelling visueel gecontroleerd; vervolgens werd met m.b.v. de Heidenhain meetunit de afwijking bepaald.
Resultaat	Zie volgblad(en) De resultaten zijn, daar waar mogelijk, getoetst aan specificatie. Afwijkingen zijn, indien mogelijk, gekenmerkt.
Onderzoeksdatum	11 juni 2014
Omgevingscondities	Temperatuur : (20,0 ± 1,0) °C
Herleidbaarheid	De bij het onderzoek gebruikte meetmiddelen zijn herleidbaar naar primaire en/of (inter)nationale standaarden.
Onzekerheid	De gerapporteerde onzekerheid is gebaseerd op een standaardonzekerheid, vermenigvuldigd met een dekkingsfactor *k=2*, welke overeenkomt met een betrouwbaarheidsinterval van ongeveer 95%. De meetonzekerheid is bepaald volgens EA-4/02.

Keuren en Kalibreren B.V.
11 juni 2014

Ing. J.A. Hemmes
Directeur

1031.841-10001
Timmerman, A.

Keuren en Kalibreren B.V.
KvK nr. 55251757
Smaragdstraat 7
7554 TD Hengelo
T +31 (0)74 250 34 44
F +31 (0)74 250 37 77
kalibraties@metriccontrol.nl

MetricControl
Bankrekeningnummer: ABNAMRO 475472217
Swift/IBAN: NL18ABNA0475472217
BIC: ABNANL2A

Reproductie van het volledige document is toegestaan. Gedeelten van het certificaat mogen slechts worden gereproduceerd na verkregen schriftelijke toestemming van het laboratorium van afgifte.

Dit document wordt verstrekt onder het voorbehoud dat generlei aansprakelijkheid wordt aanvaard en dat aanvrager

MetricControl
Geaccrediteerd conform: NEN-EN-ISO 17025:2005
Gecertificeerd conform: NEN-EN-ISO 9001:2008

CERTIFICAAT

nummer 1401778.2.1
blad 2 van 2

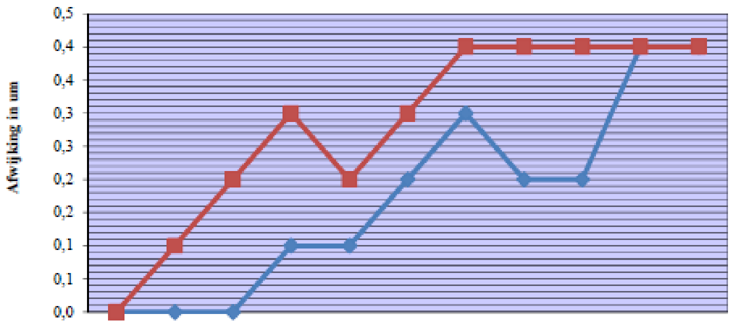
Gebruikte referentie standaarden — Heidenhain meetunit; id-nr.: X12346

Meetonzekerheid — 1,0 µm + (4,5 · 10-6 · l)

Meetresultaten

Meetpunt	Referentie waarde:	Uitgelezen waarden: ingaande taster	Uitgelezen waarden: uitgaande taster	*Gemiddeld gemeten afwijking in µm:
0	0,0	0,0000	0,0000	0,0
1	1,0	1,0000	1,0001	0,0
2	2,0	2,0000	2,0002	0,1
3	3,0	3,0001	3,0003	0,2
4	4,0	4,0001	4,0002	0,1
5	5,0	5,0002	5,0003	0,3
6	6,0	6,0003	6,0004	0,4
7	7,0	7,0002	7,0004	0,3
8	8,0	8,0002	8,0004	0,3
9	9,0	9,0004	9,0004	0,4
10	10,0	10,0004	10,0004	0,4

* Gemeten afwijking = Uitgelezen waarde - Referentiewaarde



Meting repeteerbaarheid op meetpunt met afwijk 0,4 µm

Meetpunt:	Referentie waarde:	Uitgelezen waarde:	Afwijking in µm
1	10,0	10,0002	0,2
2	10,0	10,0002	0,2
3	10,0	10,0002	0,2
4	10,0	10,0002	0,2
5	10,0	10,0003	0,3

Repeteerbaarheidsfout:	0,1	µm
Omkeerfout:	0,2	µm

LC-NA-28352-EN-N

JRC Mission

As the science and knowledge service of the European Commissio[n] the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

Joint Research Centre

EU Science Hub

Publications Office

doi:10.2789/355009
ISBN 978-92-79-64623-2